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THE SPECTRUM OF SCORPIUS XR-1 TO 50 KEV

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In this letter, a balloon observation of the strongest X-ray source in Scorpius (SCO XR-1), in which the spectrum has been obtained to 50 keV, is reported. This measurement, together with previous rocket observations, indicate the spectrum is nearly exponential, characteristic of a optically thin hot gas at 50 x 10^6 ^oK with a flatter tail above about 35 keV. The measurements reported here were obtained during the summer of 1965, and since repeated attempts at re-observation have failed, we have decided to publish these results now. Scorpius will not be in a position for further balloon study until late 1966.

The X-ray telescope which has been described in detail as a satellite instrument (Hicks, Reid, and Peterson, 1965), consists of a 3 mm thick NaI scintillation counter surrounded by a CsI anticoincidence collimating shield. The detector area is 10 cm^2, its half angle is 13^o. It has nearly unit efficiency over the 10 to 200 keV range and a resolution at 30 keV of 40%, full width at half maximum (FWHM). The detector is mounted in a servo-controlled gimbal pointing system. During flight, good events from the detector, whose rate is a few counts/sec, are converted in a 128-channel pulse-height analyzer to a digital code group. This is transmitted to receiving stations on the ground for reduction and analysis. Auxiliary information relative to the total detector counting rates, servo performance, and temperatures are also telemetered on additional channels of the PCM/FM/FM system.

The apparatus and observing technique has also been described briefly in conjunction with a subsequent observation of the Crab Nebula (Peterson, Jacobson and Pelling, 1966). In this observation the detector was fixed in elevation and controlled in azimuth to point south, using the earth's magnetic field as a reference. In this manner a source making a meridian transit passes through the detector aperture. For Scorpius, however, the reference magnetometer was mounted on a 24-hour clock with respect to the detector. A low elevation source is thus approximately tracked during its meridian transit, extending the observation time from about 1.5 hours to 4.5 hours. The earlier version of the apparatus, as used for Scorpius, did not provide for elevation and azimuth readouts independent of the servo loop.

The balloon flight was launched at 1850 CST on June 18, 1965, reached ceiling altitude of 130,000 feet at 2110, and floated level until 0645, when the apparatus parachuted to earth and was recovered. The meridian transit of SCO XR-1 occurred at about 2300 CST. During the flight the servo occasionally behaved in an erratic manner, apparently because of an unexpected coupling mode in the torsion suspension to the balloon. In this work, only data obtained when the servo was nearly at null are used. The internal evidence indicates that during these intervals the detector was indeed pointing at Scorpius, although an independent verification of the azimuth is not available. About once each hour a Ba^{133} calibration source moved into the detector aperture. The appreciable change of detector gain noted during this flight was therefore easily correctable. Minor improvements in the servo and detector have eliminated these difficulties in later flights.

The spectrum of Scorpius is obtained by subtracting the counting rates when the source was within the detector aperture from the background rates obtained before and after the transit. Because of the fixed detector elevation, there is no correction for the zenith angle dependence of this background, which consists mostly of atmospheric and diffuse cosmic X-rays, and a small number of spurious detector events. The total counting rate between 20 and 40 keV was 2.9 c/sec when the source was in the aperture and 2.0 c/sec for the background measurement. The source spectrum is obtained by correcting the difference for area, efficiency, channel width, and attenuation by the 3.3 gm/cm^2 of residual atmosphere.

The resultant spectrum is shown in Figure 1, along with data obtained by the Livermore group (Chodil, et al, 1965) (Grader, et al, 1966). Our data is based upon a 50 minute view of the source combined with a 240 minute accumulation of background and noise counts. Errors shown are standard deviations in the counting statistics. The low energy cutoff is determined by atmospheric absorption at 3.3 gms/cm^2 depth and 50^o zenith angle. Above 50 keV the spectrum is lost in the background, therefore upper limits at a 95% confidence level are indicated. The rocket measurements above the atmosphere extend to lower energies, but cut off at about 20 keV due to the low flux and the short observing time. Also indicated in the Figure are the dates of the various rocket observations, and scales appropriate to radio astronomy units. The data generally fit an exponential intensity law, which may be characteristic of a thermal bremsstrahlung at 50×10^6 ^oK, as indicated by the solid line. The fall off of the spectrum at the lowest energies has been interpreted as due to interstellar absorption (Felten and Gould, 1966). The small disagreement in the data at the lower energies may be due to instrumental effects and corrections, although the possibility of time variations in these objects should not be excluded.

At higher energies, above about 35 keV, there is apparently another component of emission. This "non-thermal tail" which extends to about 50 keV, contains a flux of about 0.03 photons/cm^2-sec. Although interpretation of these events in terms of a continuum process is most likely, the data are also consistent with a nearly monochomatic emission at about 42 keV superimposed on the exponential spectrum measured at lower energies. The probability that random events form the structure shown is only a few percent. Essentially the same results are obtained by analyzing the data over different time and pulse-height groupings. Further observations, with better energy resolution and lower background, are required to substantiate the existence of this tail.

SCO XR-1, located at about 16^{hr} 15^{m} R.A. and -15.6^{o} dec. has been the subject of considerable investigation (Gursky, et al, 1966) (Bowyer, et al, 1965)(Fisher, et al, 1966). Like most of the X-ray sources, it has not yet been identified with any known radio or optical object (Johnson, 1966). An improved location obtained by Gursky, et al (1966), who have also determined its angular size to be less than 20" of arc, may soon permit this however. This object is the brightest in the sky at 3 keV (Bowyer, et al, 1965) other than the sun. The exponential spectrum of Scorpius is much softer than the power law spectrum we have observed from the Crab Nebula (Peterson, et al, 1966) although Haymes and Craddock (1966) have recently reported an exponential spectrum from this object. At 20 keV the Crab appears brighter than Scorpius, and is in fact, more luminous than the quiet sun (Peterson, to be published). The observations suggest that the nature of the Crab Nebula is considerably different from that of Scorpius XR-1.

Initially, the X-ray sources were discussed in terms of emission from supernovae remnants (Bowyer, 1965). SCO XR-1, because of its intensity and location just out of the galactic plane, was thought to be a nearby object. The possibility of high temperature plasmas in these remnants is given considerable credibility by interpreting the nearly exponential spectrum as due to a 50×10^6 $^{\circ}$K optically thin gas. Such a model, however, has been considerably constrained because of the small angular size and lack of an obvious visible feature. Placing the object at 1000 pcs, for example, requires densities of at least 10^4 to 10^6 ionized H atoms/cm^3, with very little allowance for expansion in the unknown time since the explosion. This would also result in an object which should be optically observable. Simple neutron star models, apart from theoretical difficulties, do not give the correct spectrum.

The recent discovery of extragalactic sources (Byram, et al, 1966) brings up the possibility that this object may be at large distances. If this is so, difficulties due to densities, expansion velocities and optical size would be overcome. At one megaparsec, for example, the X-ray luminosity would be 6×10^{43} ergs/sec, which is comparable to the X-ray luminosity of M-87, whose radio and optical luminosity is about 3×10^{41} ergs/sec. The limit on the radio luminosity of SCO XR-1 (Johnson, 1966) at this distance, would be about 5×10^{35} ergs/sec. There is at present no theory linking radio, optical, and X-ray emission for the extra galactic sources.

Manley(1966), because of these problems, has suggested a new class of objects. These are protostars, passing through a certain stage of condensation, which emit X-rays via the synchrotron effect. Producing the observed exponential X-ray intensity requires an electron spectrum with a sharp cut-off at high energy. Such electron spectra have not previously been required to explain cosmic processes. Further observations of these sources are necessary to provide better foundations for theoretical development.

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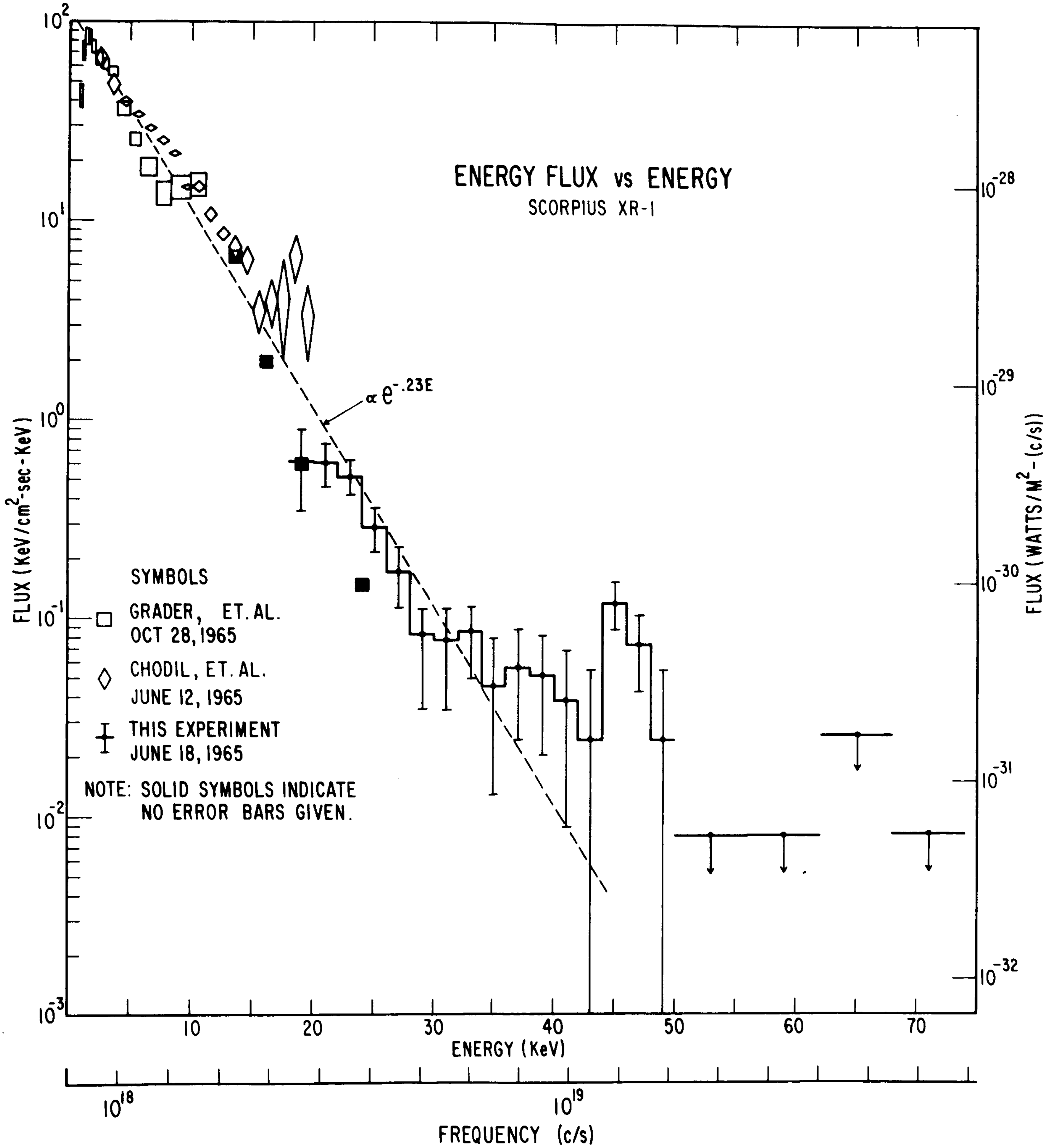

Figure 1
Various Measurements of the Spectrum of Scorpius XR-1,
along with the dates of observation